Zooplankton Aggregations Near Sills

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LONG-TERM GOALS

This project seeks to understand the biological and physical mechanisms for producing and maintaining dense aggregations of zooplankton in regions where ocean currents interact with steeply sloping coastal sills.

OBJECTIVES

The primary goal during FY02/03 was to continue work on quantitative acoustic assessment of zooplankton distributions and species in Knight Inlet, B.C., with special focus on zooplankton aggregations near the sill at Hoeya Head. The specific objectives in the recent field measurements (Nov. 2001 and Nov. 2002) were to compare the results from high-resolution multi-frequency echo-sounders with *in-situ* net samples and optical measurements, assessing the strengths and weaknesses of each approach. Ultimately, ground-truth verification of the acoustic estimates will allow assessment of broader-scale zooplankton abundances in the Inlet, insight into predator-prey interactions, and use of the data to guide behavioral modeling studies.

APPROACH

This work combined expertise in multi-frequency acoustics, conventional zooplankton net trawls, and *in-situ* camera systems in 2 separate two-week field surveys in Knight Inlet, B.C. Similar to the Nov. 2001 trials (reported last year), the Nov. 2002 trials focused on repeat transects across the sill with a vessel-based, three-frequency echo-sounder system. This data were supplemented with multi-net (BIONESS) trawls, bongo nets, and otter trawls (operated by D. Mackas and group of IOS), and profiles with a new high-resolution camera system (ZOOVIS, operated by M. Benfield of LSU). Additional broad-area acoustic and in situ surveys spanning the entire length of Knight Inlet were conducted. As before, the three echo-sounders were acoustically calibrated, allowing quantitative assessment of zooplankton abundances.

A new feature of the Nov. 2002 field trials was the use of a ship-mounted RESON 8125 multi-beam sonar. This high-resolution (455kHz, 240 x 1.0° x 0.5° beams, ~5 cm in range) sonar was used for detailed bathymetric survey of the Hoeya Head sill, and to further assess the potential for such sonars in volumetric measurements of zooplankton. Use of this expensive system, with its associated position-attitude sensors, processing software, and operator training was contributed to the project by Defence R&D Canada.

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14. ABSTRACT
This project seeks to understand the biological and physical mechanisms for producing and maintaining dense aggregations of zooplankton in regions where ocean currents interact with steeply sloping coastal sills.

15. SUBJECT TERMS

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Oceanographic conditions in the Inlet were determined with an acoustic Doppler current-meter, moored 110 m deep just west of the sill, and with CTD casts taken throughout the entire Inlet.

WORK COMPLETED

A two-week field survey on board the *CCGS Vector* was conducted in Knight Inlet Nov. 12 to 24, 2002. A vessel-based three-frequency (38, 120, and 200 kHz), narrow-beam echo-sounder system was operated by the author during the field trials. The hull-mounted transducers on the *CCGS Vector* were replaced in mid-2002, requiring some modification of the system electronics and a complete acoustic re-calibration. This echo-sounder was used for transects across the sill and wide-area surveys in other areas of the inlet, and for comparison with BIONESS samples and profiles with in situ optical devices. During acoustic surveys the ship maintained a speed of close to 6 knots (relative to the ground). The echo-sounders recorded data up to 200 m depth with pulse lengths near 37 cm and a ping-rates of 1 Hz.

A RESON 8125 multibeam swath-bathymetric sonar, modified for water volume sampling was operated on specific occasions. A detailed bathymetric survey of the sill at Hoeya Head was performed on Nov. 21, 2002. The survey was composed of 21 parallel lines approximately 1.0 nautical mile in length with line spacing of 100 m. After some post-processing, the raw survey data was reduced to a geo-referenced, tidally-corrected 5 x 5 m bathymetric grid. This bathymetric data was made available to the other co-PI's, and is available to any other interested ONR-funded investigators. Additionally, the RESON multi-beam sonar was evaluated for volumetric imaging of fish schools, zooplankton layers, and turbulent billows.

Recent, ongoing work has focused on quantitative comparisons between the multi-frequency acoustic scattering and abundance-species information from the BIONESS trawls and ZOOVIS. A scientific manuscript on this work is under preparation. Additionally, the reconciliation of acoustic and in situ abundance estimates then allows wide-area acoustic survey data to be used in conjunction with on-going zooplankton behavior modeling currently being pursued by Mackas, Allen, Tsurumi, and Ianson (see Mackas et al. annual report).

RESULTS

The high-resolution vessel-based echo-sounders produced dramatic images of the complex internal hydraulic flows and resulting zooplankton and fish distributions in the vicinity of the sill. Figure 1 shows a representative example from the 120-kHz sounder as the ship traveled westwards over the Hoeya Head sill. The 120-kHz sounder proved to be the most useful in viewing the overall water column, as it was sensitive to both fish and zooplankton aggregations and backscatter from turbulent microstructure. The figure shows the typical internal hydraulic flow separation and down-welling jet that forms on the ebb tide (described in Farmer & Armi 1999; Klymak & Gregg 2001). BIONESS trawls in the flow region recovered negligible amounts of large zooplankton, suggesting that the distinct flow lines observed in the upper 60 m were due to turbulent micro-structure backscatter. Conversely, below 60 m depth during daylight hours there was a strong biologic scattering layer (dominated by 16-mm-long *Euphausia pacifica*), with dense aggregations often appearing on the (in this case former) upstream side. The general composition of the zooplankton aggregations can be deduced from the relative levels of the three echo-sounder frequencies; krill layers are seen in the 120 and 200-kHz channels but only faintly in the 38-kHz. One small 'fish' school roughly 15 m high can be seen above the western slope of the sill near 100 m depth. These generic 'fish' schools have a similar scattering strength at all three frequencies. Several Otter trawls were taken through these benthic aggregations, suggesting that these schools were composed of prawns, dogfish, and small bottom fish, presumably feeding on the dense swarms of Euphausiids that accumulate against the sill.

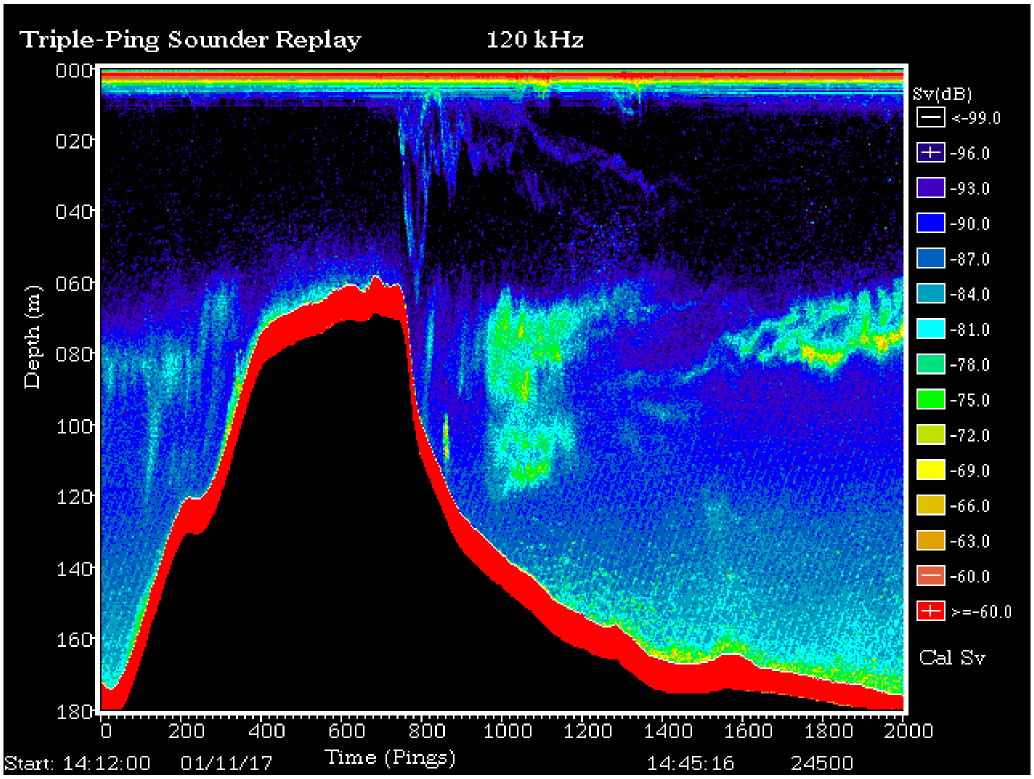


Figure 1: Volume Scatter Strength vs. depth and time for vessel-mounted 120kHz echo-sounder during westbound transect over the Hoeya Head sill during early ebb-tide (flow from left to right), 1412h to 1445h Nov. 17th. Total horizontal distance approximately 6 km.

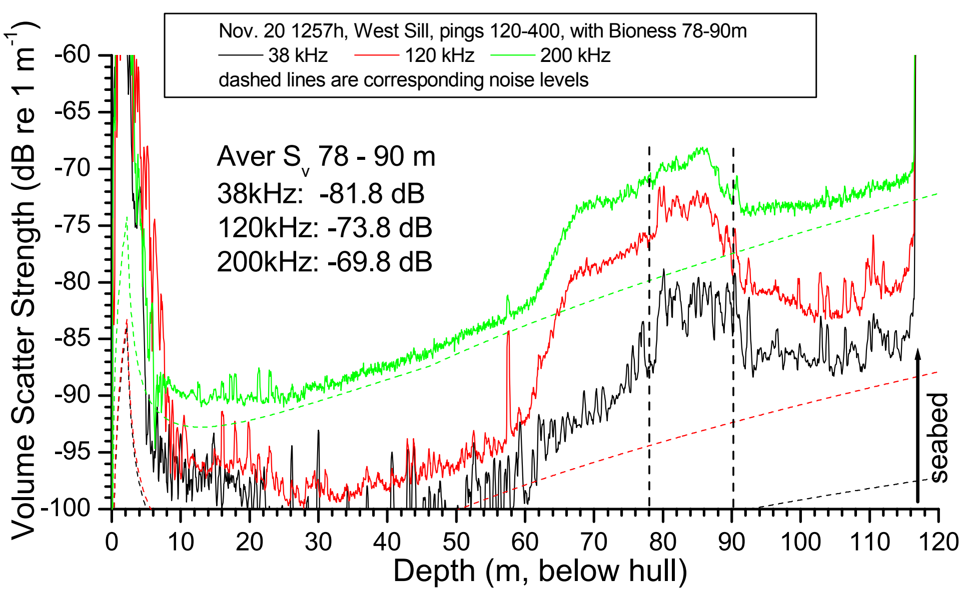


Figure 2: Three-frequency comparison of volume scatter strength vs. downward range from vessel-mounted echo-sounders near western slope of Hoeya Head sill, Knight Inlet, 1257h Nov. 20th, 2002. Krill layer is evident at 66 – 90 m, coincident with BIONESS trawl through the region.

Figure 2 shows a comparison between short-time-averaged profiles at the three echo-sounder frequencies for a krill aggregation observed near western slope of the sill. The krill layer at 66 to 90 m depth is clear, exhibiting an increasing scattering strength with frequency as expected for animals in the Rayleigh to geometric scattering transition region. The ratio between the 200 and 120 kHz scattering strength is near 4 dB. A coincident BIONESS trawl at 78-90 m found Euphausiids of length 16 ± 1.5 mm with average abundance of 8.7 per m^3. Using length- and orientation-averaged scattering models due to Stanton et al. (1993), the averaged scattering strengths yield corresponding abundances of 39, 8.5, and 8.1 per m^3 for the 38, 120, and 200-kHz sounders, respectively. The agreement for the 120 and 200-kHz channels is excellent, with the overestimate at 38-kHz likely due to contamination from fish scattering. Through careful comparisons of this kind, various classes of acoustic scattering models can be verified.

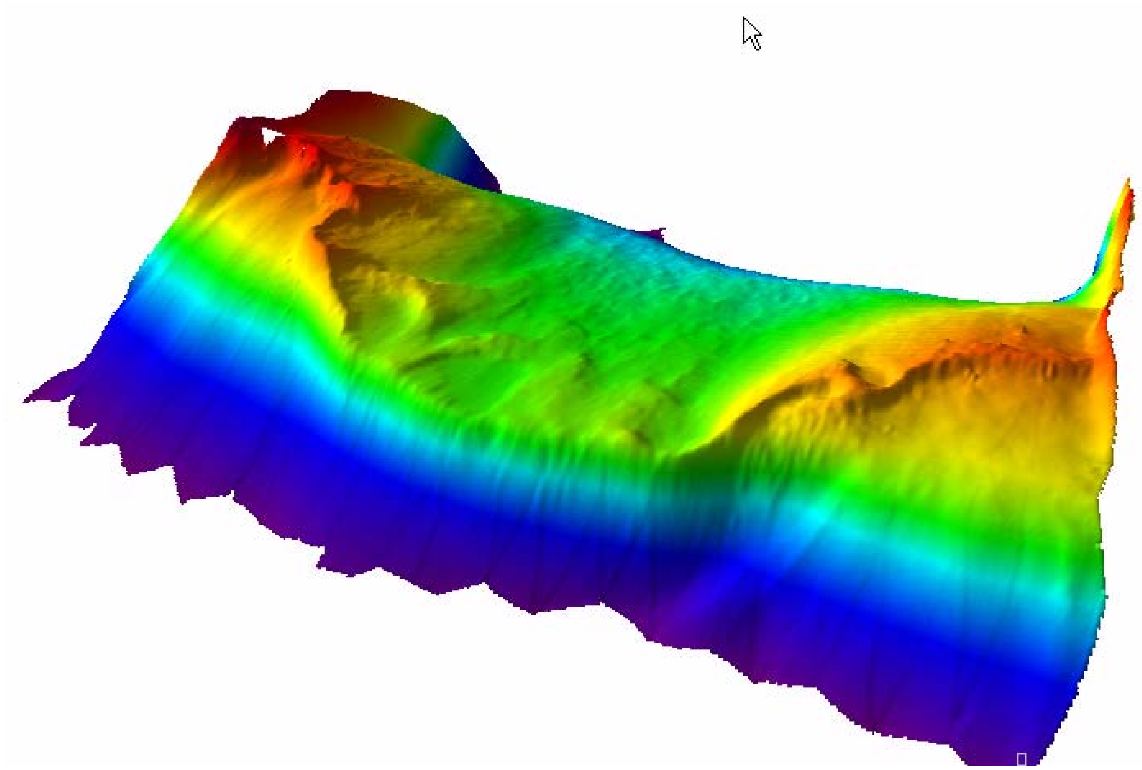
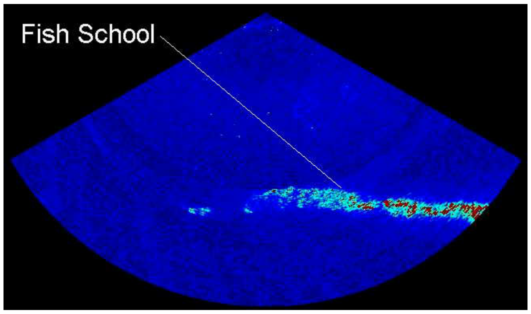


Figure 3: three-dimensional view looking NE of bathymetric survey data from sill at Hoeya Head, Knight Inlet. Color-coded depths vary from 115 m (violet) to 20 m (red). Central sill crest (in green) is at 62 to 65 m depth. North-south distance is approximately 1.8 km.

Owing to its importance to the overall flow and resultant zooplankton aggregations, a detailed bathymetric survey of the sill at Hoeya Head was performed on Nov. 21st using the RESON 8125 sonar, with result shown in Figure 3. The survey spanned water depths from 115 m on the east and west sides of the sill to 20 m in the shallows on the north and south sides of the inlet.

(a) 

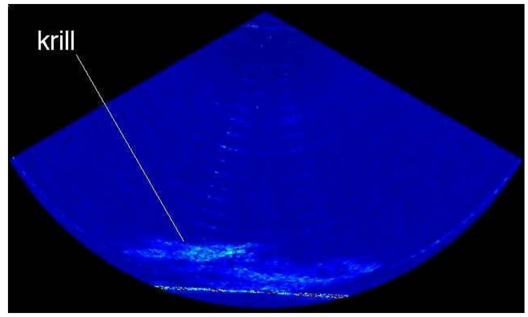
(b) 

Figure 4: Raw intensity images from the RESON 8125 in volume sampling mode: a) mid-water fish school, and b) krill layer near bottom. Images show a 120° athwartships sector to 120 m range.

Additionally, the RESON multi-beam sonar was able to image the across-track extent of fish schools and zooplankton layers. In this mode the sonar was set to maximum gain, transmit power, pulse length (290 μs), and range (120 m) at a ping-rate of roughly 0.2 Hz (a processing limitation). Example images are shown in Figure 4. This opens the door to combining these RESON images with the single-beam sounders to create a quasi-3-d picture, although significant improvements in the data handling are required to make this a useful capability. For this first attempt, simultaneous echo-sounder data can also be used to generate an ad hoc calibration for these raw images.

IMPACT/APPLICATIONS

It is hoped that this work and subsequent analysis will provide a better understanding of:
1. the links between zooplankton spatial aggregations, predator species (such as planktivorous fish), and physical oceanographic phenomena.
2. the efficacy of combining multi-frequency acoustic with in situ plankton sampling techniques such as nets trawls and optical systems.
3. the validity of various existing acoustic scattering models of zooplankton in the context of multi-species and multi-sized zooplankton populations.

Ongoing work by the author and co-PI's will be focused on writing of scientific manuscripts along these themes.

RELATED PROJECTS

This project is coupled with projects headed by D. Mackas from IOS and M. Benfield from Louisiana State Univ., with the common aim of understanding zooplankton aggregations at the Knight Inlet sill. D. Mackas is responsible for coordination of ship-time on the *CCGS Vector*, and along with his group at IOS for operation of an instrumented BIONESS trawl, an Otter trawl, and subsequent processing of the zooplankton samples. M. Benfield is developing and testing an in situ optical zooplankton imaging system (ZOOVIS).

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